

**"STUDIES OF PLASMA FLOW PAST  
JUPITER'S GALILEAN SATELLITES"**

**NASW-98014**

**Final Report**

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## **STUDIES OF PLASMA FLOW PAST JUPITER'S GALILEAN SATELLITES**

### **FINAL REPORT:**

**7/1/98 - 6/30/01**

#### **1. Introduction**

In this report, we describe work performed under Contract NASW-98014, awarded to Science Applications International Corporation, for the period 7/1/98 to 6/30/01. We have investigated the interaction of Io, Jupiter's innermost Galilean satellite, with the Io plasma torus, using our semi-implicit time-dependent 3D MHD code to model the plasma interactions. We have used the same code to model the plasma interaction at Ganymede.

#### **2. Plasma Flow Past Io**

##### **2.1 Investigation of the First Galileo encounter with Io**

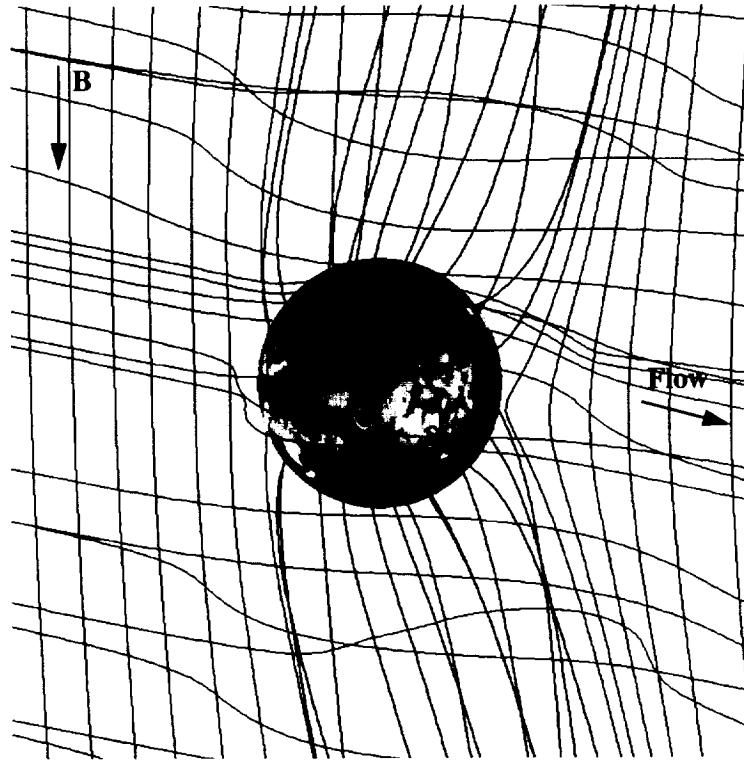
The Galileo spacecraft's first encounter with Io (referred to as J0) occurred December 7, 1995, with a closest approach distance of 898 km. The flyby revealed an unexpectedly large depression in the ambient (Jovian) magnetic field in Io's wake, suggesting that Io might be intrinsically magnetized (Kivelson et al. 1996ab). However, the spacecraft also encountered a high density plasma environment near Io (Frank et al. 1996; Gurnett et al., 1996a), suggesting that a highly conducting Io ionosphere and significant ion pickup could account for the magnetic field perturbations. Our computations [Linker et al., 1998] have succeeded in describing many of the observed features of the plasma flow past Io, including the depression in the magnetic field and the low velocity, low temperature, and high density of the wake region, for both magnetized and conducting models of Io (both cases include the ion pickup process in Io's exosphere). However, there were important quantitative differences between the simulation results and the observations, such as the double-valley structure of the magnetic depression and the large increase in velocity and temperature on the flanks of Io that were not reproduced by the simulations (conducting or magnetized).

We investigated a number of possible reasons for these discrepancies. One possibility we studied is whether substantially higher ion pickup could account for the double-peak depression observed in  $|B|$ . If additional pickup is to account for this depression, it must occur on Io's flanks where the velocity is highest (Figure 1

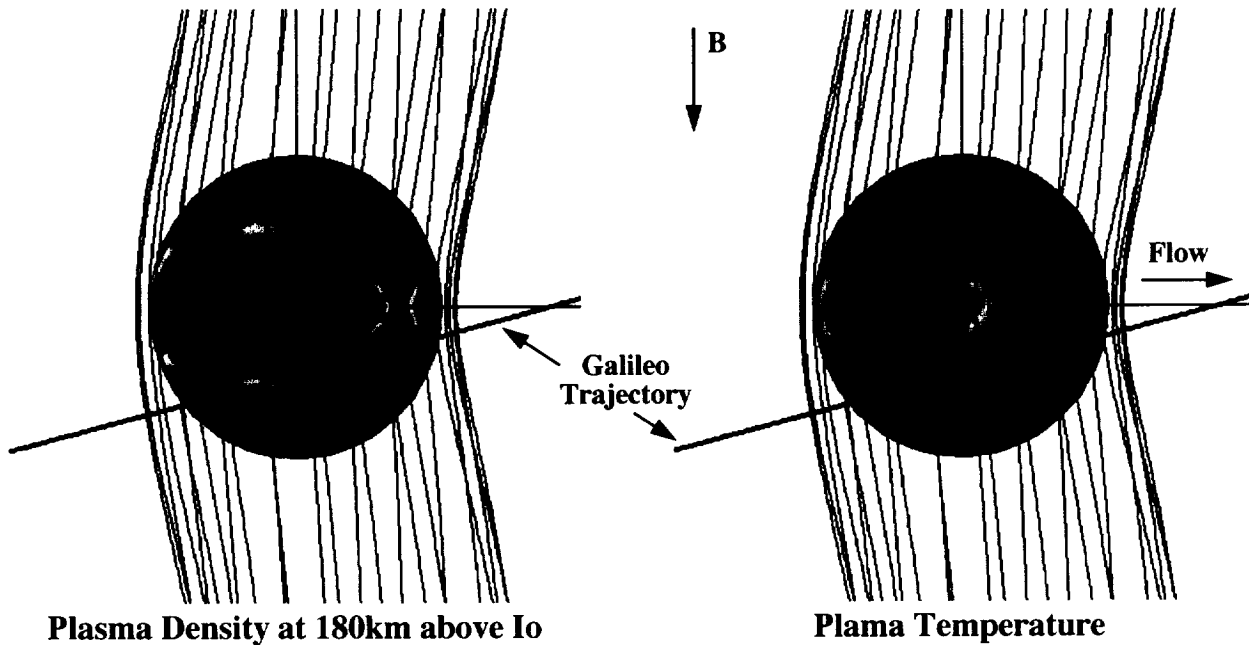
shows magnetic field lines and flow stream lines from a typical simulation). This is the region where ionization and charge-exchange can convert flow energy to thermal energy most efficiently, thereby increasing the pressure and reducing  $|B|$ . Thus far we have found that increasing the ion pickup rates does not seem to improve the agreement. The observed acceleration of the plasma flow on the flanks of Io is about a factor of 1.7, which is close to the value one gets when no mass loading is present (1.9). Increasing the ion pickup rates tends to lessen the plasma flow speed. For our simulations with substantial ion pickup, the flow speed is only about 1.3 times the background flow speed, indicating that the ion pickup rate there may already be too high to account for the observations.

The observations of high plasma densities in Io's wake suggest that ion pickup is very active near the satellite, but increasing the ion pickup rate takes too much momentum and thermal energy out of the plasma. These results suggested to us that we need another energy source that balances the double-peak depression observed in  $|B|$ . We have investigated whether ohmic heating from the closure of field-aligned currents generated at Io could provide this source. In our energy equation (cast as an equation for pressure) the  $\eta^2$  term has previously been neglected. We neglected this term since  $\eta$  is not easily deduced from observations;  $\eta$  is effectively a free parameter. However, neglecting this term entirely clearly underestimates the contributions of local plasma processes to the pressure, as large currents have been observed to flow at Io [Acuna *et al.*, 1981]. We found that inclusion of ohmic heating can make up for some of the thermal energy lost through ion pickup, but only a small quantitative change occurs in the overall results.

Another possible source for these differences could be related to our assumptions about the neutrals near Io responsible for ion pickup. Unfortunately, Galileo has no instrumentation for *in situ* measurements of the neutral density. To obtain information about the neutral species, we must rely on remote sensing. For example, remote sensing of sodium has given us important clues about the structure of Io's exosphere [Schneider *et al.*, 1991]. Sodium is a minor species, and acts as a tracer of the overall structure. Inferring the overall neutral density requires a knowledge of the sodium mixing ratio. Observations of the major neutral species (S, O, and SO<sub>2</sub>) can help to remove this ambiguity.

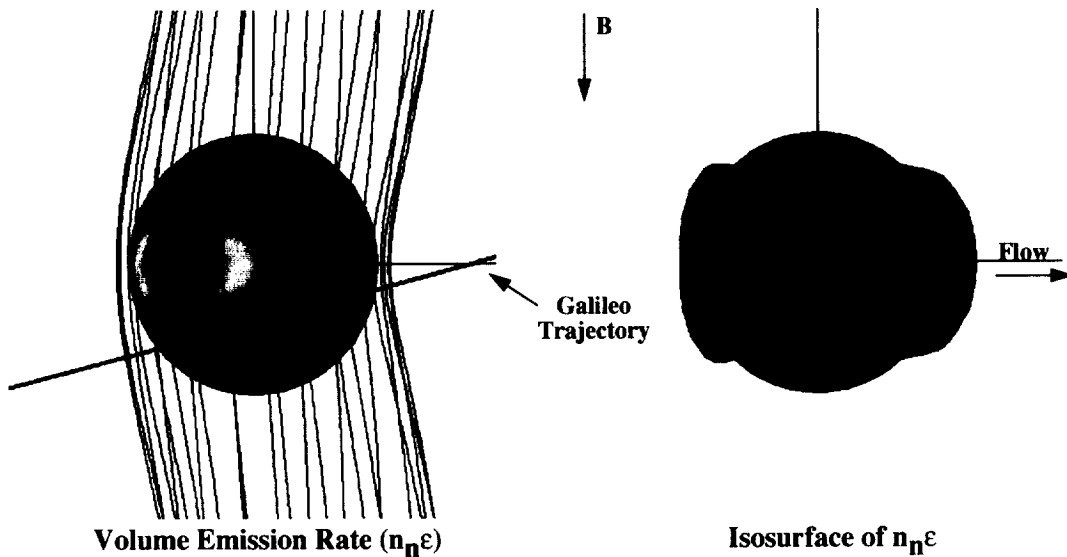


**Figure 1.** Magnetic field lines (blue and black) and plasma flow streamlines (green) from an MHD simulation of Io's interaction with the plasma torus. Black field lines connect to Jupiter at both ends; blue field lines are connected to Io at one end and Jupiter at the other end. The plasma flow is diverted around Io and the "Alfven Wing", a standing Alfvenwave perturbation where currents flow that bend the local magnetic field. In this simulation Io was assumed to have an intrinsic magnetic field. The flow and field patterns for conducting and magnetized models of the Io interaction show many similarities, which is why the question of Io's possible magnetism was not settled by the original encounter.



**Figure 2.** The plasma density and temperature contoured on a sphere 180km above the surface of Io from an MHD simulation of a conducting, unmagnetized Io. Red shows the largest values and bluepurple the smallest. The plasma density peaks in Io's wake and in the Alfven wing; the plasma temperature is smallest in those regions. Magnetic field lines (black) outside of Io, and the trajectory of Galileo in 1995 are also shown.

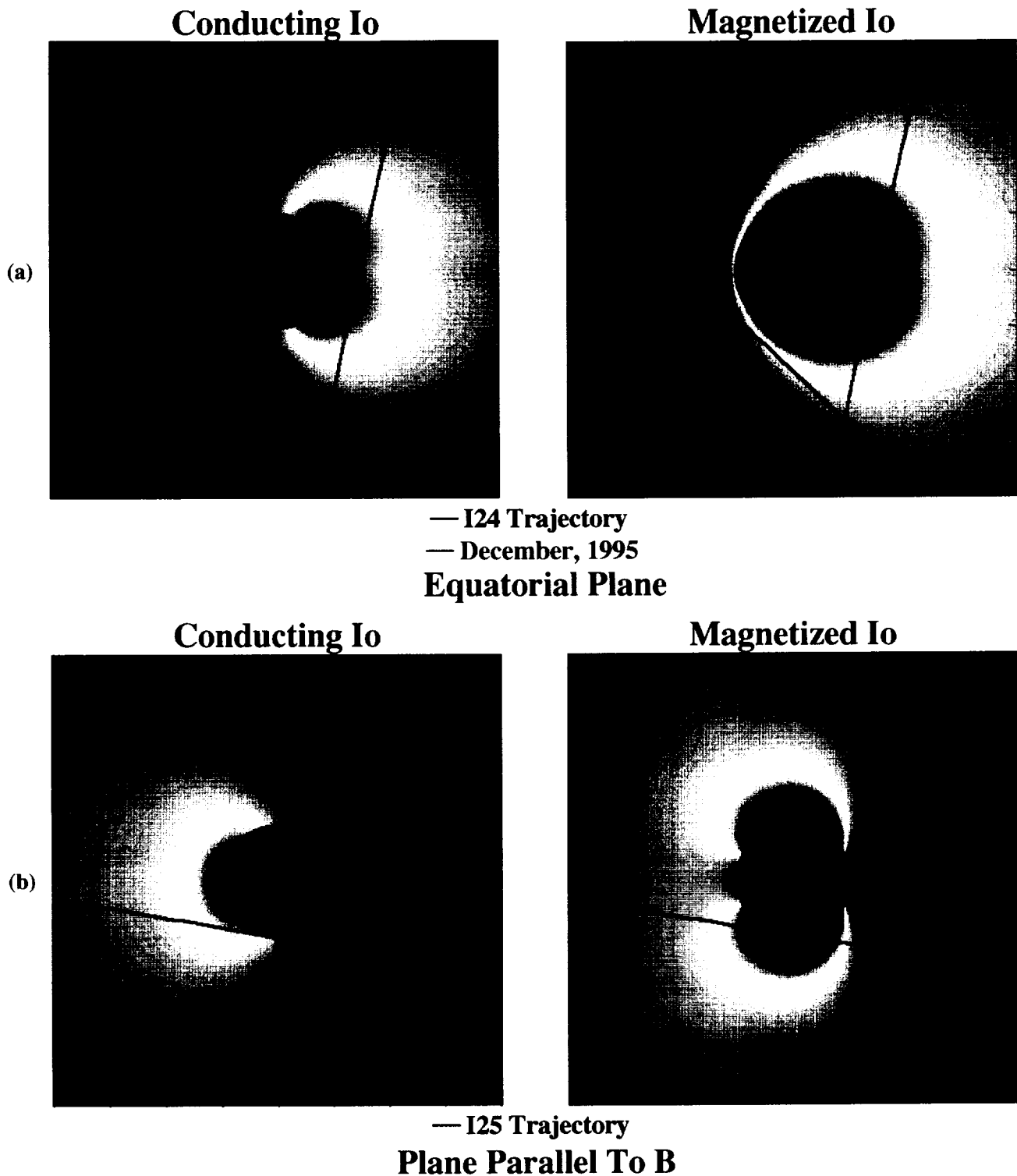
The Space Telescope Imaging Spectrograph (STIS) instrument aboard Hubble Space Telescope (HST) has imaged Io in several spectral lines, and these observations have revealed important details about the spatial structure of neutral sulfur (SI) and neutral oxygen (OI) emissions near Io. These observations give us a direct measure of two of the major constituents of Io's atmosphere and exosphere. These ultraviolet emissions are excited by electrons in the local plasma impacting the emitter. By using the plasma parameters from our MHD simulations to model the ultraviolet emissions, we can use HST data and Galileo observations together to infer properties of Io's neutral atmosphere and the plasma environment near Io.



**Figure 3.** (a) The volume emission rate at 1356A contoured on a spherical surface 180 km above Io, for the same simulation as Figure 2. Red shows the highest emission, and bluepurple the smallest. Also shown are magnetic field lines and the Galileo trajectory from the 1995 flyby. (b) An isosurface of the volume emission rate. Comparing Figure 3 to Figure 2, we see that the regions of highest density also have very low temperatures (corresponding to less than 1 eV for the electrons) and emission is quenched there.

We have investigated what the plasma properties from our simulations predict about ultraviolet (UV) emissions near Io. As an example, Figure 2 shows the plasma density and temperature from the simulation, and Figure 3 shows the corresponding volume emission rate predicted by the simulation. To calculate the emission, the electron temperature (which is responsible for the UV emissions) is assumed to be a fixed fraction of the total plasma temperature (which is predicted by the simulation). Even though the plasma density is greatly increased in the wake, the coincident low plasma temperature predicts a small emission in the wake. On the flanks of Io, the plasma temperature is large enough to produce significant emissions. As the collisional excitation process that causes the ultraviolet emissions

# **Magnetic Field Magnitude at Io with Projected Trajectories**



**Figure 4.** The magnetic field magnitude projected trajectories for the original J0 encounter (December 19995) and the I24 and I25 encounters. (a) The plane passing through Io's equator. Note that there are not great differences in the predicted values for the conducting and magnetized models.. (b) The plane parallel to the background magnetic field and the I25 trajectory. The magnetized model predicts a much greater perturbation to  $|B|$ .

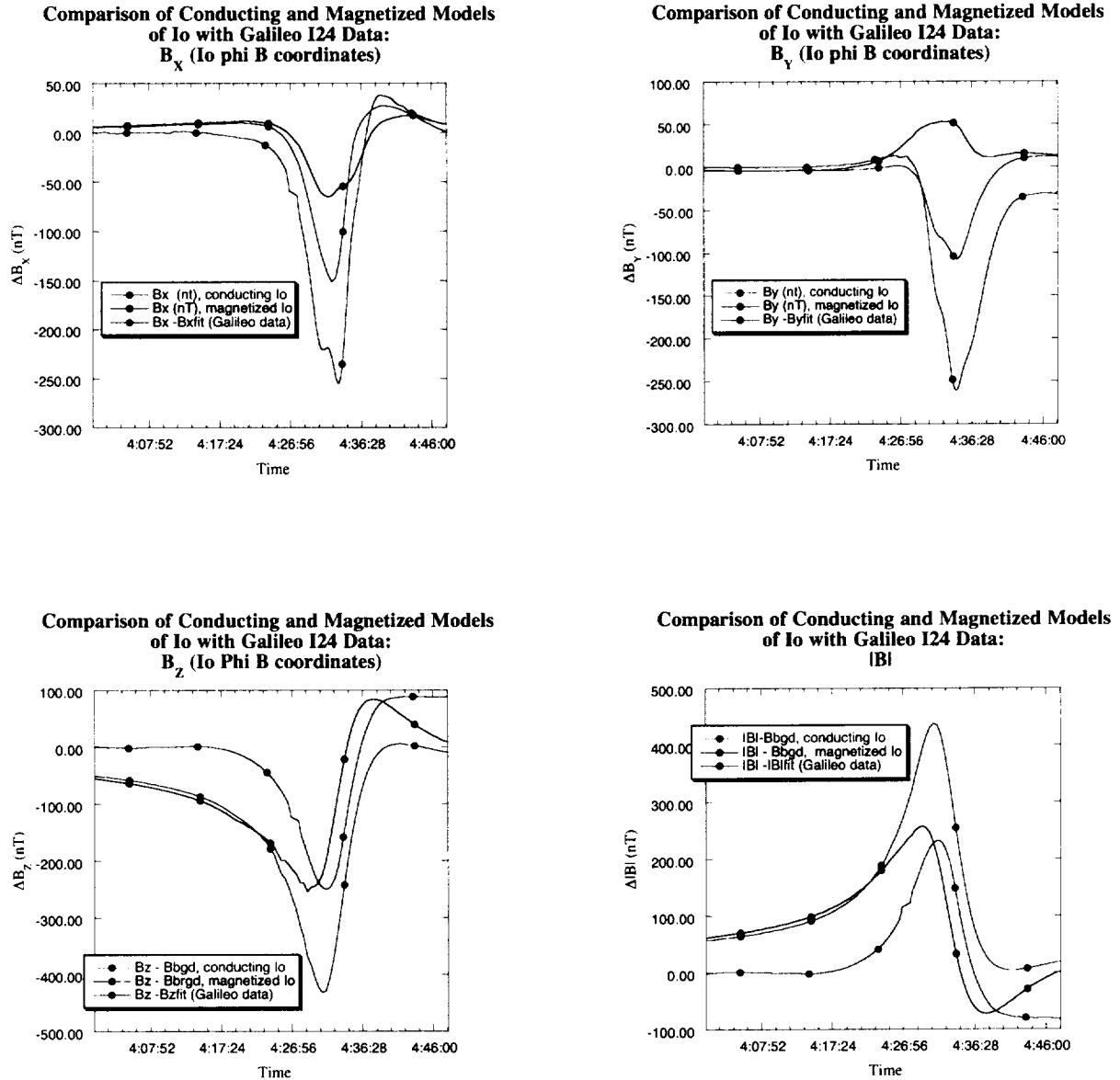
is very similar to electron impact ionization, observations of UV emissions give us a snapshot of where ionization is likely occurring. We have used this ion pickup source rates in the MHD model based on the computed volume emission rates as a proxy for ionization. We found that this helps to raise the plasma pressure in the flanks of Io and lessens the discrepancy with the Galileo observations. This is a topic that warrants further study in the future.

## **2.2 The I24 and I25 flybys**

The first of three new flybys of Io by Galileo occurred on October 11, 1999 (referred to as I24). In the original flyby of Io (referred to as J0), the Galileo spacecraft flew through Io's wake with a closest approach distance of 898 km. The I24 trajectory passed by Io upstream and on the flanks of Io, with a closet approach distance of 611 km. From the point of view of simple potential (current-free) magnetic field models, one might expect that for an Ionian dipole moment approximately aligned with the local (Jovian) magnetic field one would see a depression in the local magnetic field both well upstream and downstream of Io. This would be in contrast to what is expected for a conducting Io, where draping of the magnetic field upstream of Io causes the local magnetic field strength to increase while the currents driven in the conducting region reduce the field strength downstream of Io. However, the situation at Io is more complicated, because even if Io does have an intrinsic magnetic field, significant ion pickup must also be occurring and this will cause slowing of the flow and draping of the magnetic field. Figure 4a illustrates the difficulty in using measurements of the magnetic field strength from the I24 flyby to determine whether or not Io is magnetized. Shown in the figure is the "equatorial plane" from MHD simulations of the interaction, with the Galileo J0 and I24 trajectories projected onto this plane. One sees that the region of depressed magnetic field upstream of Io in the magnetized case is closely confined near Io and not likely to be penetrated significantly by the I24 flyby.

On November 26, 1999, the Galileo flew past Io in the I25 encounter, approaching within 300 km of Io. The trajectory for this encounter was quite different than I24. Figure 4b shows the magnetic field strength in the plane parallel to both the local background magnetic field and the corotational flow with the I25 trajectory projected onto this plane. One sees that in the magnetized case, near the poles of Io, the magnetic field strength becomes easily discernable from the background field. Unfortunately, except for the plasma wave (PWS) data, all of the

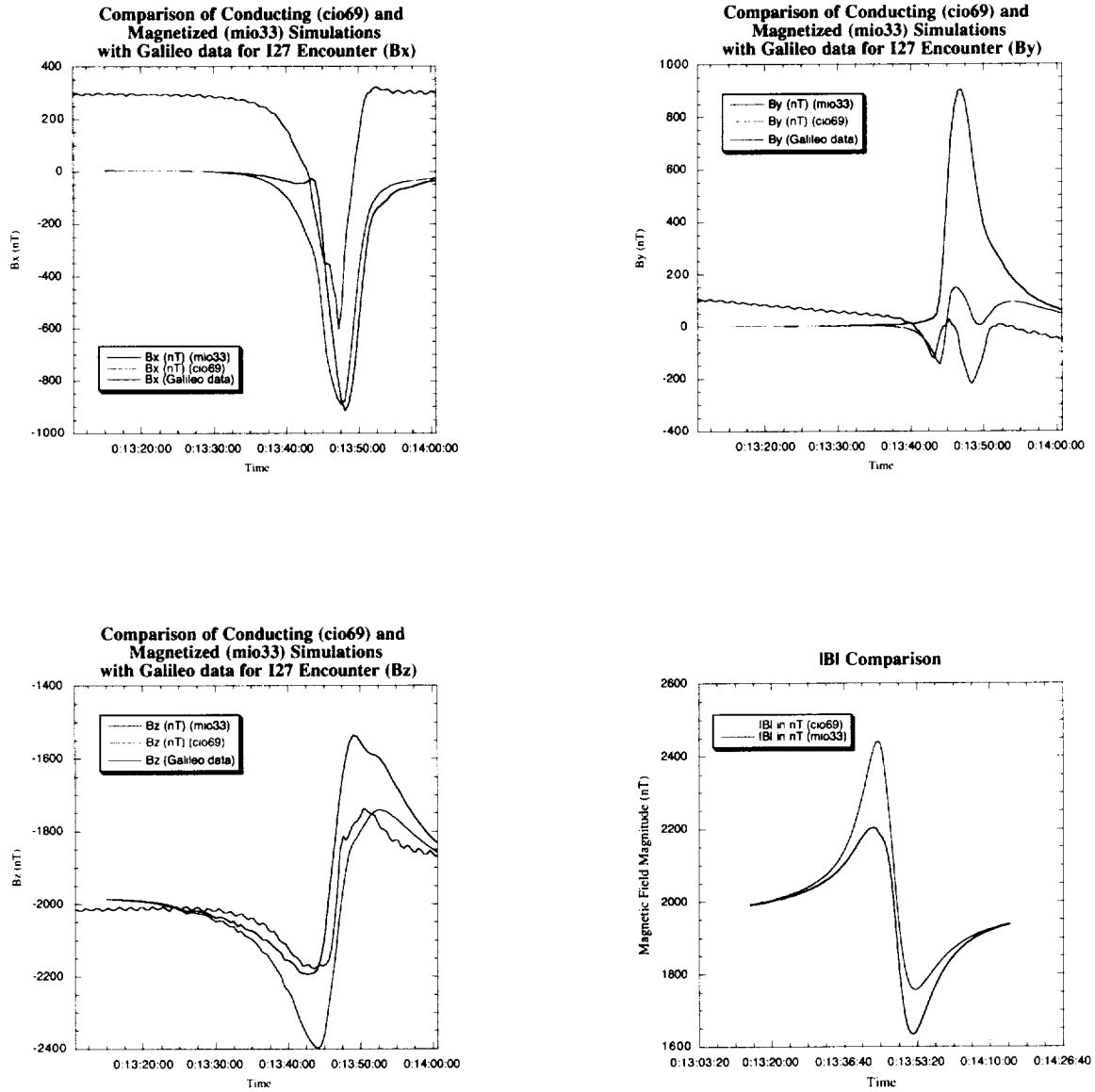
# I24 Comparison



**Figure 5.** Comparison of MHD simulations of Io's interaction with the plasma torus and Galileo magnetometer data.



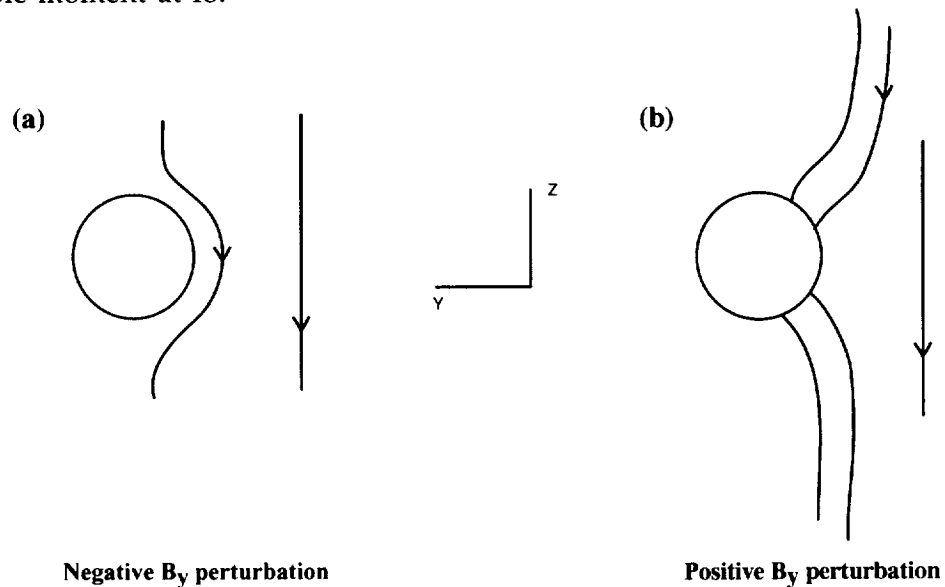
# I27 Comparison



**Figure 6.** Comparison of MHD simulations of plasma flow past Io with the Galileo data for the I27 encounter. Note the large  $B_y$  perturbation predicted in the magnetized case.

particles and fields measurements were lost during the I25 encounter, negating the opportunity to easily settle the question of intrinsic magnetization at Io.

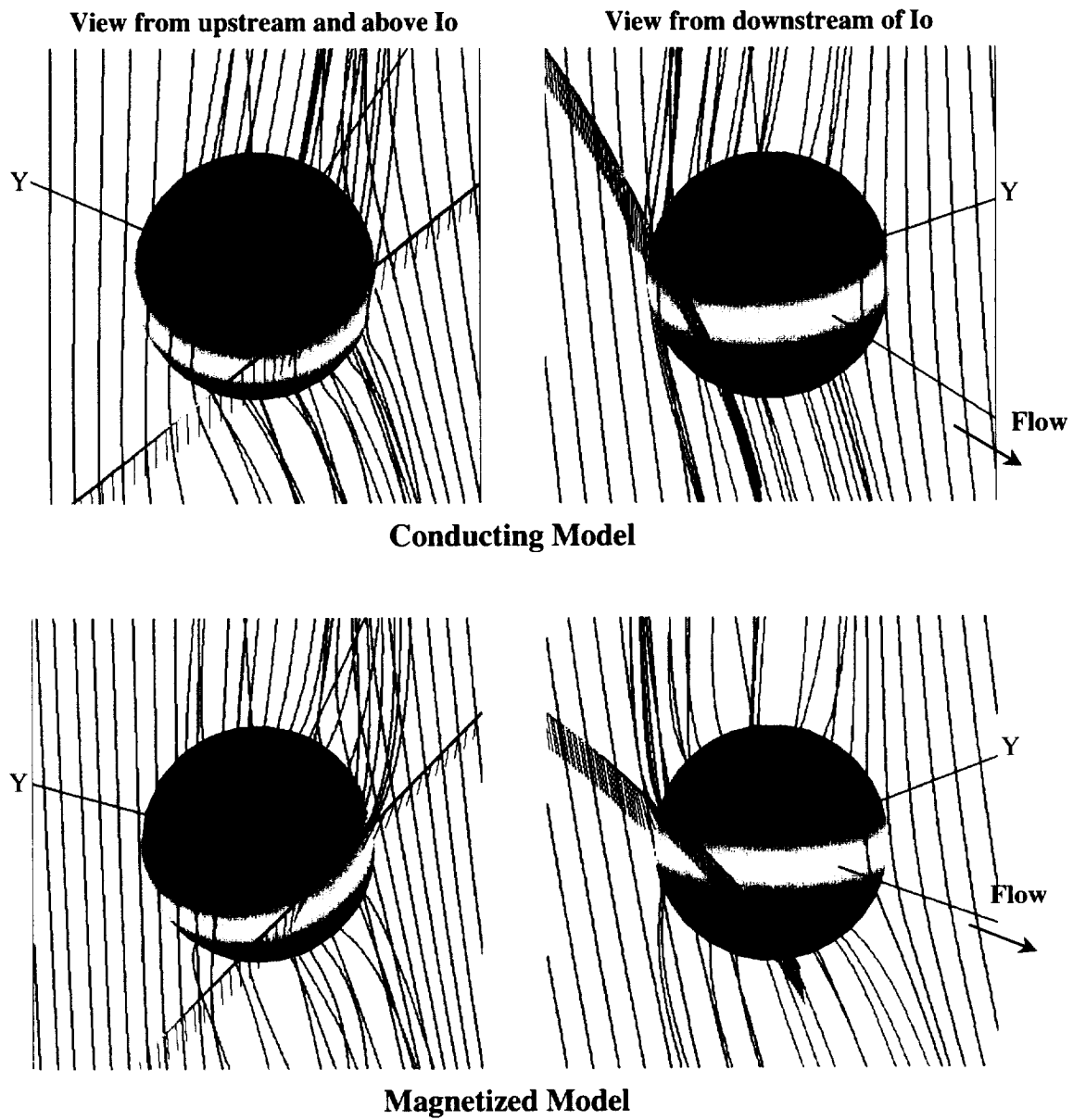
Figure 5 shows a comparison of conducting and magnetized simulations with the Galileo I24 data. The magnetized model of Io yields too small a signature for the  $B_x$  component and the wrong sign for the  $B_y$  component. The  $B_z$  component and  $|\mathbf{B}|$  are predicted reasonably well. The conducting model gets the right sign of the perturbation for all components, although it misses the change in sign in the  $B_z$  perturbation near the end of the encounter. The conducting model underestimates the perturbation to  $B_x$  and  $B_y$  but overestimates the  $B_z$  perturbation. Given the discrepancies between both models and the data, this flyby cannot rule out either model, although it places some constraints on the magnitude and tilt of an intrinsic dipole moment at Io.



**Figure 7.** Perturbation to  $B_y$  on the flanks of Io for conducting (a) and magnetized (b) models of Io.

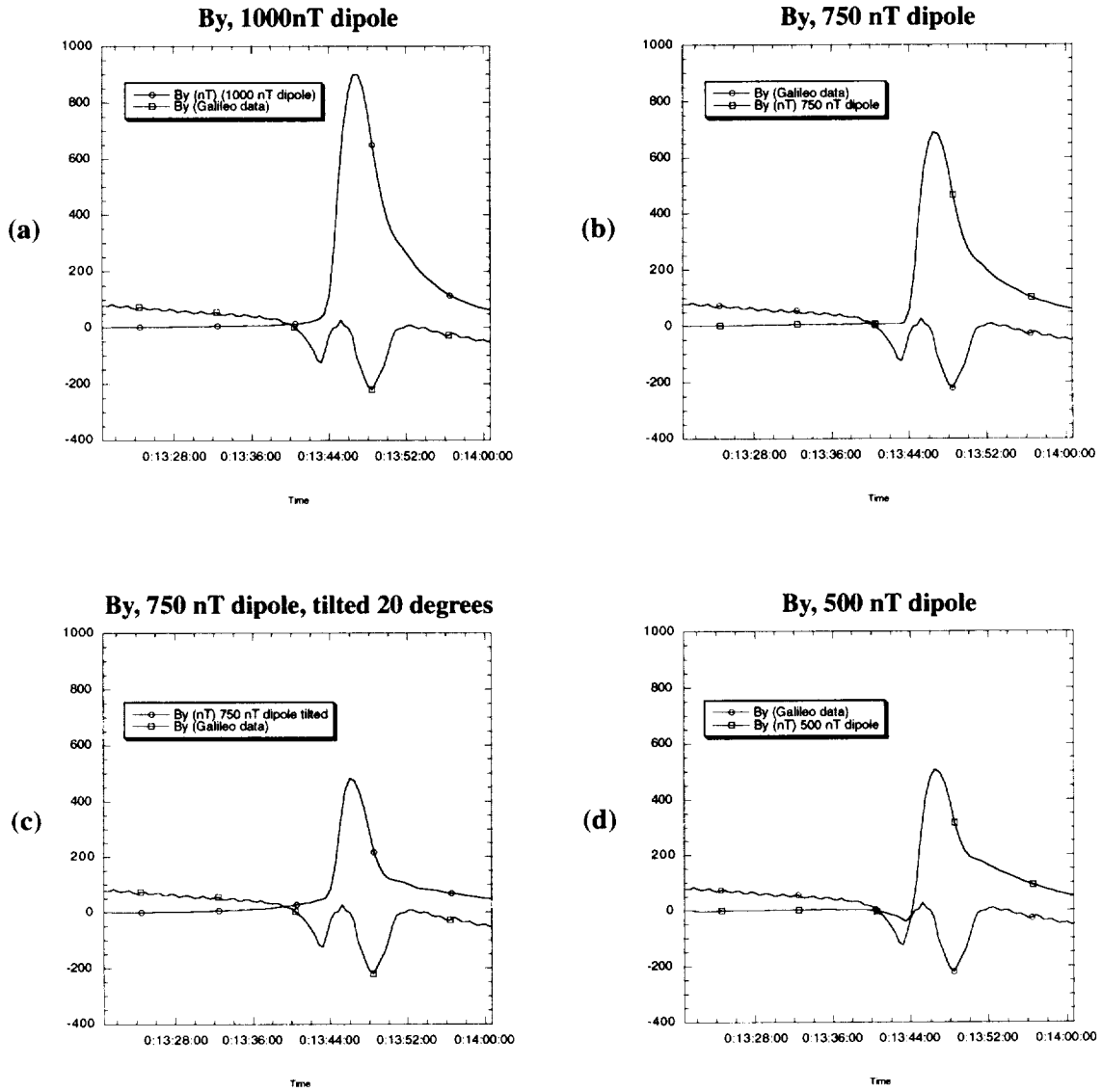
### 2.3 The I27 Flyby

The Galileo I27 encounter occurred on February 22, 2000, with a closest approach distance of 199 km. At first glance, the trajectory is similar to the I24 encounter, but the much closer approach of the spacecraft yielded some important clues about the nature of the interaction. Figure 6 shows a summary comparison of the conducting and magnetized models of Io. Note that the magnetized model predicts a strongly positive  $B_y$  perturbation, in contrast to the conducting model and



**Figure 8.** Views of the I27 trajectory and magnetic field lines from a conducting model of Io (top panels) and a magnetized model (lower panels). Flow is along the X direction, and Y is towards Jupiter.

moment at Io. A talk discussing these results was presented by Linker, Kivelson and Walker (2000) at the Fall AGU meeting in San Francisco.



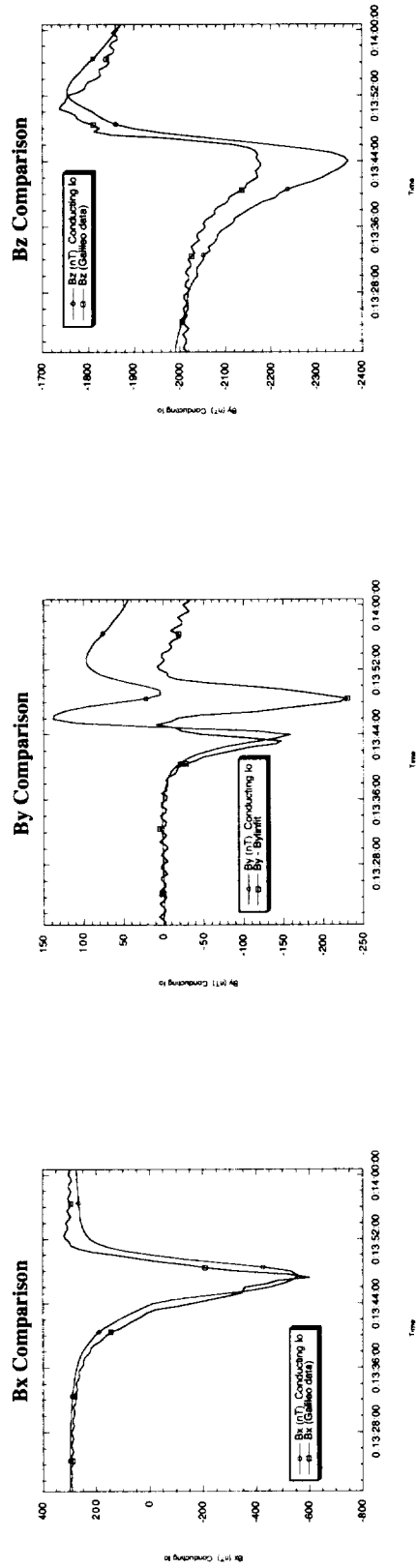
**Figure 9.** Comparison of the By perturbation from simulated I27 flybys for 4 different MHD simulations of plasma flow past an intrinsically magnetized Io: (a) 1000 nT dipole (value at the equator in the absence of a background field) aligned with Jovian spin axis. (b) 750 nt dipole. (c) 750nT dipole 20 degrees from Jovian spin axis. (d) 500 nT dipole.

to the Galileo data. Figure 7 shows schematically why there is a big difference in the perturbation to  $B_y$  predicted by conducting and magnetized models of Io. In the I27 pass Galileo flew close enough on the flanks of Io that the predicted magnetic field measurements are very sensitive to the differences between the two models.

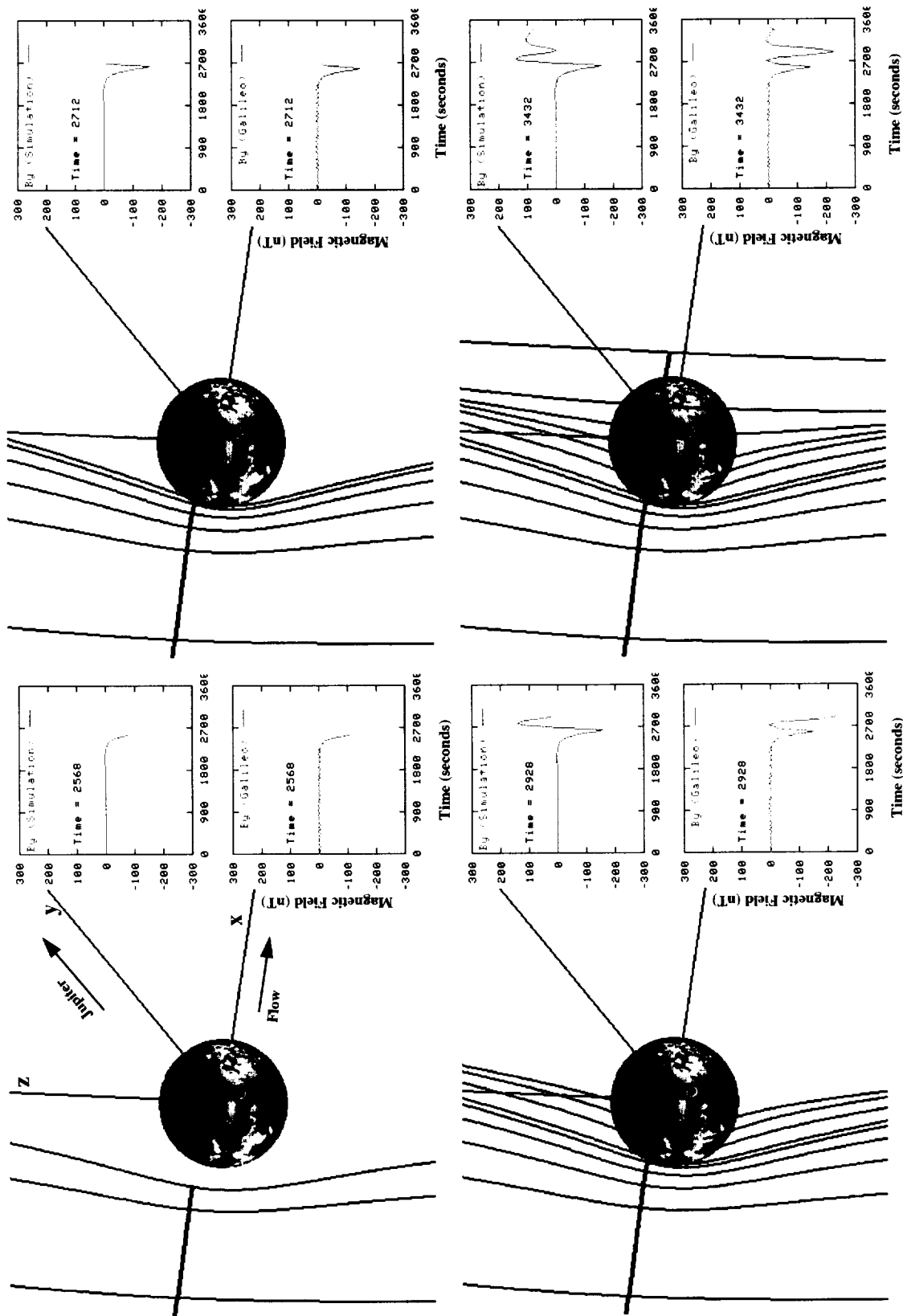
Figure 8 shows magnetic field lines near Io for both magnetized and conducting cases. The Galileo trajectories are colored lines in these plots, with the color indicating the magnetic field strength (red largest, blue smallest). The lines attached to the trajectory are magnetic field vectors extracted from the simulation along the trajectory. These views show how the draped field lines in the conducting model (top two panels) have the correct  $B_y$  perturbation, while in the magnetized model (bottom two panels) the inward bending of the field gives a  $B_y$  perturbation in the wrong direction. Figure 8 shows schematically the basic difference in the perturbation to  $B_y$  predicted by conducting and magnetized models of Io for the I27 pass. The lack of a positive  $B_y$  perturbation in the data is inconsistent with magnetized model.

To investigate to what extent these results constrain a possible intrinsic magnetic field at Io, we performed four MHD simulations of the Io interaction with smaller dipole moments and different tilts. For the I27 encounter, potential (current-free) field models of the interaction do a poor job of predicting the signature because they do not include the sweep-back of the field by the ambient flow or the twist in the field from the currents in the Alfvén wings. Therefore, investigation of possible tilts to an intrinsic field, or the signature of smaller dipole moments, requires performing full MHD computations.

Figure 9 shows a comparison of these results. Figure 9a shows a case with a 1000nT dipole (equatorial value at the surface in the absence of a background field). The Io dipole moment is assumed to be approximately aligned with the Jovian spin axis (tilted about 15 degrees from the background (Jovian) magnetic field near Io. This case is clearly ruled out by the Galileo measurements; the  $B_y$  perturbation is an order of magnitude too large and of the wrong sign. Reducing the magnitude of the dipole moment to 750nT with the same tilt (Figure 9b) reduces the magnitude of the  $B_y$  perturbation but the change in  $B_y$  is still of the wrong sign and too large. The bipolar structure of the perturbation is also not reproduced. Introducing an additional 20 degree tilt in the Y direction (Figure 9c), or reducing the magnitude of



**Figure 10.** Comparison of an MHD simulation of plasma flow past Io with Galileo I27 data. A conducting model of Io was assumed. The red lines show a simulated flyby using the MHD model results; the black line shows the Galileo data.



**Figure 11.** A sequence showing magnetic field lines (blue lines) intersecting the Galileo I27 trajectory (thick black line) and the corresponding simulated and measured traces of  $B_y$  (red lines), for a conducting model of Io. A background trend for  $B_y$  in the Galileo data has been subtracted out. (a) As the spacecraft approaches Io, draping of the magnetic field lines produces a negative  $B_y$  perturbation. (b) As the spacecraft begins to encounter field lines that intersect Io, the draping signature is reduced. (c) As the spacecraft moves away from Io and draped field lines are encountered again,  $B_y$  swings back towards negative values. (d) Moving farther from Io,  $B_y$  returns to its background values.

the dipole moment to 500nT, also does not correct these problems. These results suggest that there is not a significant intrinsic magnetic dipole moment at Io.

We have studied the results from our simulations to see if a conducting model of Io can account for some of the detailed features observed in the data. Figure 10 shows a comparison of a simulated Galileo flyby through an MHD simulation (for the conducting Io model) with the magnetic field measurements from the I27 encounter. The simulation results quantitatively reproduce the measured  $B_x$  signature and are qualitatively similar for  $B_y$  and  $B_z$ .

Both the simulation and I27 Galileo data show a "double perturbation" to  $B_y$ . This is clearly not just a simple draping signature. To understand the underlying cause of this unusual feature, we have studied the structure of the magnetic field lines that are sampled in the simulated flyby. Figure 11 summarizes our results. As the spacecraft approached Io, it encountered magnetic field lines that drape around Io and give the expected negative  $B_y$  perturbation. Near closest approach, the spacecraft encountered field lines that intersected Io; these field lines no longer have a draping topology. Moving away from Io the spacecraft encountered draped field lines again before returning to unperturbed background fields. The simulated  $B_y$  trace is "shifted" toward positive relative to the Galileo measurements; this discrepancy could be a result of assumption in the model for the conductivity in the interior of Io. Despite this discrepancy, the model appears to have captured the timing of the changes to the  $B_y$  perturbation remarkably well.

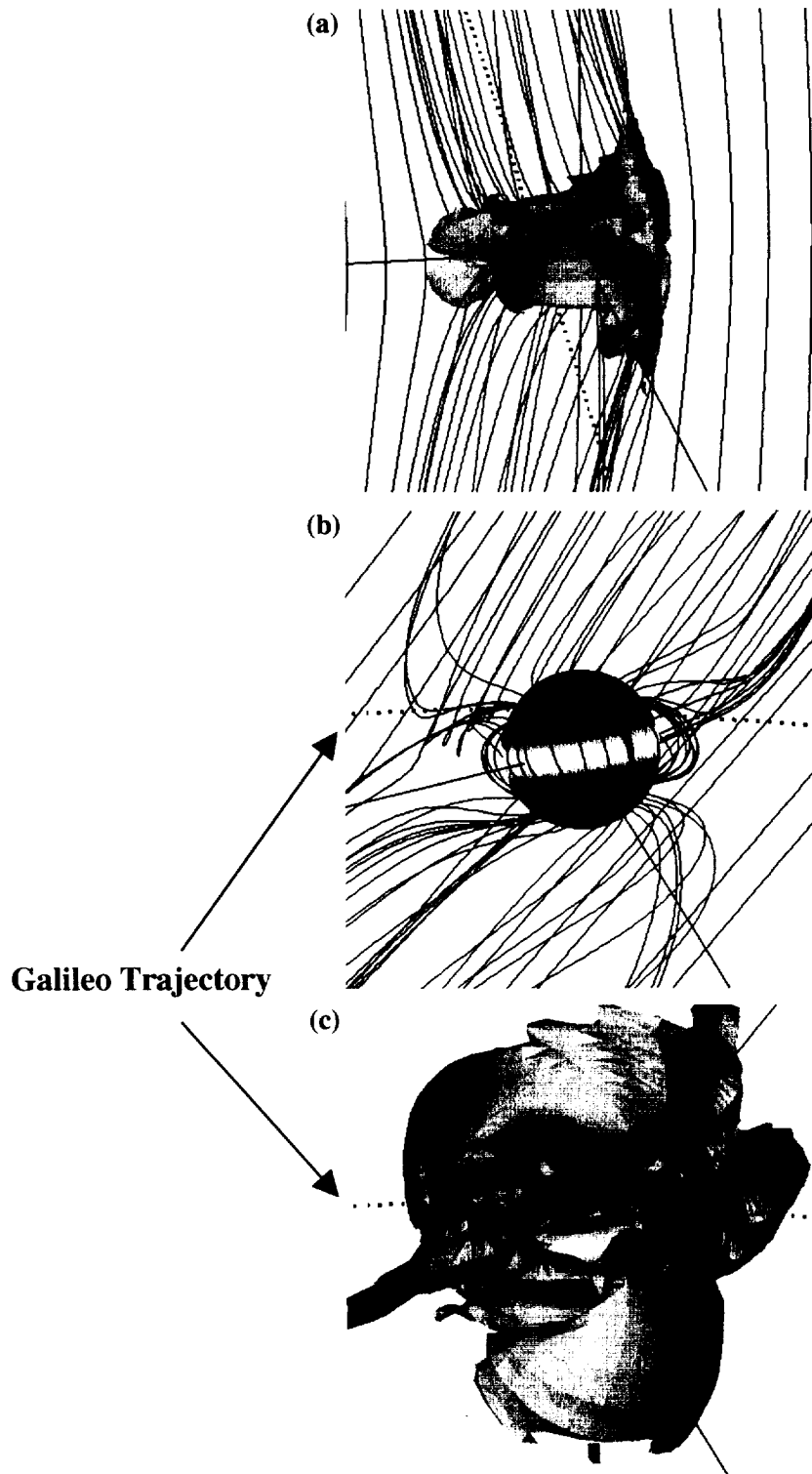
Our results suggest that Io has both a conducting ionosphere and significant ion pickup (features that are necessary to produce the results seen in all of the flybys) but does not have an intrinsic dipole magnetic field. A successful polar pass by Io in August of this year can confirm or refute these results.

### 3. The Plasma Interaction at Ganymede

We have also performed further analysis of our simulations of the Ganymede magnetosphere. One of the most surprising finding of the Galileo mission is that Ganymede has an intrinsic magnetic field [Gurnett *et al.*, 1996b; Kivelson *et al.*, 1996c]. The potential (current-free) solution used by Kivelson *et al.* to analyze the measurements matches the data quite well when Ganymede was in low beta regions of the Jovian magnetosphere (as occurred in the first three encounters). However, in these passes, it is clear that currents are present at crossings of the magnetopause



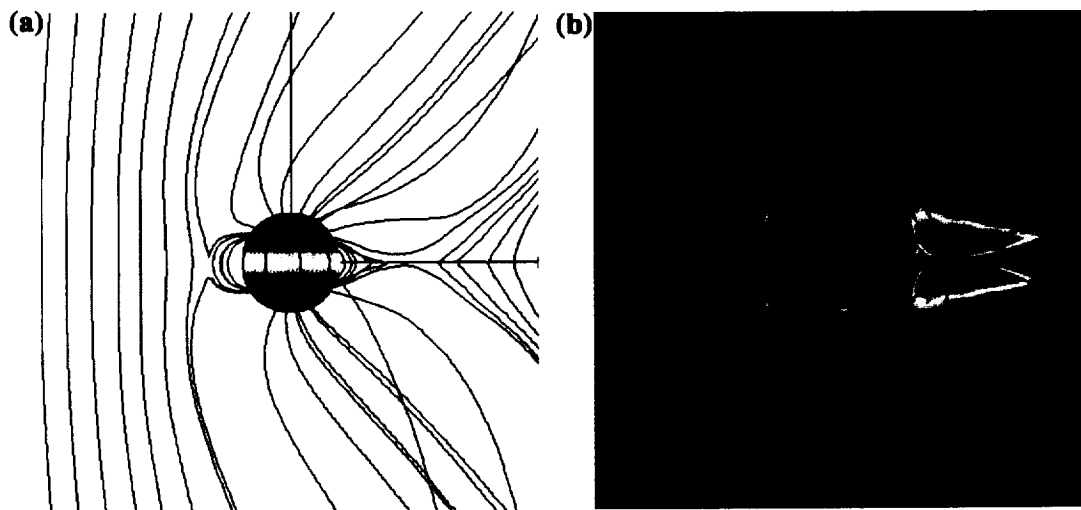
## Galileo's Path Through the Ganymede Magnetosphere: Field Lines and Current Density Isosurface



**Figure 12.** Magnetic field lines and currents in the Ganymede magnetosphere for the G1 encounter. The gold surface is an isosurface of the current density. Black field lines are connected to Jupiter at both ends, magenta field lines have one footpoint at Jupiter and one footpoint at Ganymede, and green field lines have both footpoints on Ganymede. (a) View from Jupiter. (b) Angled view from downstream showing field lines and the Galileo trajectory (red dashed line). (c) The same as (b) showing the current density isosurface.

and Alfvén wing current system. Figure 12 shows magnetic field lines and isosurfaces of the current density for an MHD simulation of the Ganymede magnetosphere for the G1 encounter, which occurred on June 27, 1996. The Galileo trajectory is shown as a red dashed line.

In G8 encounter (May 7, 1997), Galileo flew past Ganymede when the satellite was embedded in the plasma sheet, where the plasma is considerably warmer and denser. The G8 encounter was also particularly interesting because the Jovian and Ganymede magnetic fields were nearly antiparallel at the Ganymede magnetopause, making magnetic reconnection most favorable. To investigate the structure of the Ganymede magnetosphere during for this encounter, we performed a simulation using the full MHD equations, also including the effects of ionization (shown in Figure 13). Figure 13a shows magnetic field lines; the structure associated with a classic reconnecting magnetosphere can be seen. The short length of the magnetotail is because of the low Alfvén Mach number of the flow at Ganymede. Figure 13b shows the plasma velocity (black vectors) and magnitude of the current density (color map with red largest, blue smallest) in Ganymede's equatorial plane. Ganymede's magnetopause is well defined by the current density, with slow flow occurring inside the closed field region. Downstream, in Ganymede's magnetotail, larger currents, a convection pattern, and acceleration of the flow further downstream are present.



**Figure 13.** Results from a simulation of plasma flow past Ganymede for the approximate conditions of the G8 encounter. (a) Magnetic field lines near Ganymede. Red field lines are connected to Jupiter at both ends, green field lines are connected to Ganymede at both ends, and black fields are connected to both Jupiter and Ganymede. (b) Plasma velocity vectors and the magnitude of the current density ( $|J|$ ) in the plane perpendicular to the background magnetic field and parallel to corotation. Red shows the largest current density and blue the smallest.

A spherically symmetric distribution of neutrals was assumed to exist around Ganymede for this case. Ionization causes the plasma density to build up near Ganymede, especially inside the closed field region. The results from the PWS instrument during the G1 encounter show high densities near Ganymede at high latitude. In contrast, standing waves measured by the magnetometer during the G8 encounter imply a low density in the closed field region. These results suggest that ionization is not spherically symmetric near Ganymede. One reason for this may be that warm electrons don't easily penetrate into the closed field region, so that the only significant ionization occurs at high latitudes.

#### PUBLICATIONS

Kivelson, M. G., J. Warnecke, L. Bennett, S. Joy, K. K. Khurana, J. A. Linker, C. T. Russell, R. J. Walker, and C. Polanskey, Ganymede's magnetosphere: Magnetometer overview, *J. Geophys. Res.* **103**, 19963, 1998.

Kivelson, M.G, K. K. Khurana, C. T. Russell, M. Volwerk, S. P. Joy, R. J. Walker, C. Zimmer, and J. A. Linker, Magnetized or unmagnetized: Ambiguity persists following Galileo's encounters with Io in 1999 and 2000, *J. Geophys. Res.*, in press, 2001.

Linker, J. A., K. K. Khurana, Kivelson, M. G., and R. J. Walker, MHD Simulations of Io's interaction with the plasma torus, *J. Geophys. Res.* **103**, 19867, 1998.

Linker, J.A., R. Lionello, Kivelson, M. G., and R. J. Walker, Comparison of MHD models of plasma flow past Io with the Galileo flybys, manuscript in preparation, 2001.

This contract supported 3 invited and 9 contributed presentations at scientific meetings. A comprehensive paper describing comparisons with the 1999-2000 Io flybys is currently in preparation.

#### REFERENCES

Acuna, M. H., F. M. Neubauer, and N. F. Ness, *J. Geophys. Res.* **86**, 8513, 1981.

Frank, L. A., W. R. Paterson, K. L. Ackerson, V. M. Vasyliunas, F. V. Coroniti, and S. J. Bolton, *Science* **274**, 394, 1996.

- Gurnett, D. A., E. C. Stone, and N. Murphy, *Science* **274**, 391, 1996a.
- Gurnett, D. A., W. S. Kurth, A. Roux, S. J. Bolton, and C. F. Kennel, *Nature*, **384**, 535, 1996b.
- Kivelson, M. G., K. K. Khurana, R. J. Walker, C. T. Russell, J. A. Linker, D. J. Southwood, and C. Polanskey, A magnetic signature at Io: Initial Report from the Galileo Magnetometer, *Science*, 273, 337, 1996.
- Kivelson, M. G., K. K. Khurana, R. J. Walker, J. Warnecke, C. T. Russell, J. A. Linker, D. J. Southwood, and C. Polanskey, *Science* **274**, 396, 1996b.
- Kivelson, M. G., K. K. Khurana, C. T. Russell, R. J. Walker, J. Warnecke, F. V. Coroniti, C. Polanskey, D. J. Southwood, and G. Schubert, *Nature*, **384**, 537, 1996c.
- Linker, J. A., K. K. Khurana, Kivelson, M. G., and R. J. Walker, *J. Geophys. Res.* **103**, 19867, 1998.
- Schneider, N. M., D. M. Hunten, W. K. Wells, A. B. Schultz, and U. Fink, *Astrophys. J.* **368**, 298, 1991.

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